DECISION-AIDING AUTOMATION FOR THE EN-ROUTE CONTROLLER: A HUMAN FACTORS FIELD EVALUATION

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ABSTRACT

The CTAS Descent Advisor (DA), is designed to enable efficient transitions from the en-route to the arrival phase of flight. DA provides the en-route controller with computer generated advisories that conform to flow rate constraints.

Test controllers interacted with DA to access and perform an initial evaluation of DA advisories during a field evaluation conducted at the Denver Air Route Traffic Control Center in the Fall of 1995. Test controllers coordinated advisories with sector controllers who issued DA-based clearances during the evaluation.

A part-task human factors assessment indicated that sector controllers were able to use DA advisories for efficient and precise descent management. Sector controllers were willing to refer to and evaluate advisories, and where appropriate, provide information about alternative scenarios. Furthermore, sector controllers provided moderately high acceptance ratings for the system concept. They also reported that in the part-task context of the test, advisories were used without a general increase in workload.

INTRODUCTION

The Center-TRACON Automation System (CTAS) is designed to provide decision-making assistance to controllers by presenting planning functions and clearance advisories. CTAS considers runway separation requirements to maximize the number of aircraft that may be scheduled to the available runways. This results in increased throughput (Erzberger, 1992).

To maximize the benefits available from the CTAS system, increased accuracy in gate crossing times is needed from the en-route controller. This accuracy will improve throughput efficiency as well as significantly reduce fuel consumption through the reduction in the number of corrective clearances needed to separate aircraft in the en-route airspace. The Descent Advisor (DA), the CTAS en-route decision support tool, is designed to assist air traffic controllers by supporting efficient transition from the en-route to the arrival phase of flight. DA provides the controller with advisories to simultaneously detect and resolve conflicts while conforming to required traffic management constraints (i.e., metering or miles-in-trail). These advisories include fuel-efficient top-of-descent (TOD) and speed profile (cruise and descent), new cruise altitude, and vectors. The vertical profiles represented by the advisories are designed to mimic those generated by advanced FMS systems. Conflict resolution and traffic management conformance advisories are supported by automatic, semi-automatic and provisional trial planning functions.

While increased throughput, reduced delays and optimized descent profiles all provide clear benefits to air carriers, it is important to consider the effect that modifications to current procedures and the introduction of a new system may have on controller workload. For example, possible changes in desired accuracy of crossing times and potential increases in throughput may combine to increase workload to unacceptable levels.

DA provides advisories with the intent of redistributing workload from tactical controller actions to strategic controller planning. Highly accurate trajectory predictions (Williams and Green, 1998, Green & Vivona, 1998) will reduce the need for corrective clearance updates and, therefore, workload. However, introducing another source of information that must be processed, integrated and evaluated carries its own burden on resources. Alternatively, advisories may reduce the amount of mental calculations and such that the controller must perform. It is important to ensure, through evaluation, that controller workload is maintained or decreased with the introduction of CTAS procedural modifications and advisories.

An additional area for investigation is controller acceptance of changes to the current operating environment. Controller acceptance could be contingent on a number of issues, ranging from system reliability and accuracy to user interface and operational procedures. It is important to identify elements of the system that may be unacceptable to controllers early in the development process, when these issues can be addressed effectively and efficiently.

Incremental field testing has been conducted at the Denver, Air Route Traffic Control Center (ARTCC). The first of these activities, the 1992 DA Flight Test, involved validating trajectory prediction accuracies (Williams & Green, 1998). The test focused on trajectory prediction accuracy and pilot procedures. Controller participation was limited to issuing pilot discretionary descents to a NASA B737, when possible. Controllers did not evaluate advisories, or modify their procedures or phraseology during this test. Therefore, no observations or controller ratings were collected.

The 1994 DA Preliminary Assessment extended previous assessments to include revenue flights (Green, et al., 1995). This activity provided the first opportunity for researchers to work with pilots and controllers to implement DA clearance advisories in the field.

A third field assessment, the Initial DA Evaluation (IDE) served as a significant extension to the previous evaluations. The IDE, conducted at the Denver ARTCC from September through November of 1995, involved three airlines (United, MarkAir, and Mesa), and a variety of nine aircraft types including jets (conventionally- and FMS-equipped) and turboprop commuters. The results of this field test will be described in this report.

The IDE provided the first test conditions in which test controllers, who were full performance level controllers not signed onto control positions during the test periods, physically interacted with a prototype DA user interface called the auxiliary display interface (ADI). Additionally, a published descent procedure was developed in conjunction with the FAA and airline representatives (Palmer, et al., 1997). The development of this procedure allowed the use of specific phraseology tailored for DA, instead of the pilot discretionary descent used in earlier evaluations. Clearance advisories were generated (speed profile, altitude, and vectors) to meet conflict-free arrival metering times and issued to aircraft prior to descent. DA clearances were issued to 185 commercial flights during the IDE. Trajectory prediction accuracy was assessed with results indicating a mean accuracy of 0.5 seconds late with a standard deviation of 14.3 seconds (Green & Vivona, 1996).

Primary goals of the human factors portion of the assessment were to investigate the effects of evaluating and issuing DA-based clearances and assess the workload associated with the use of a published descent procedure and modified controller phraseology. Information was also gathered about the use of the prototype user interface. Data included questionnaires regarding workload and system acceptance, debriefing interviews to address specific issues that arose during the traffic period, recordings of air/ground communications and observations of the interactions with the ADI.

METHODS

Equipment

A network of SUN computers was used to run the CTAS software version 4.3.0t, which included Traffic Management Advisor (TMA) and DA. TMA is the CTAS tool that generates arrival metering schedules. DA generates controller advisories to provide the fuel-efficient profile by which the aircraft can meet the TMA-generated scheduled time.

A BriteLite computer with a 13” monitor was used as the primary controller display. This ADI provided an alphanumeric display of advisories for each arrival flight. This display approach was used to simulate the type of display possible on current FAA PVD/HOST hardware. Test controllers used a mouse and keyboard to interact with the system.

The alphanumeric display provided aircraft state and advisory information grouped by arrival gate. The following information was provided for each aircraft: aircraft call sign, scheduled time of arrival, delay, current speed (Mach/IAS), speed advisory lock condition, speed advisory, descent profile advisory, path stretch or vectoring advisory and predicted meter fix crossing restriction violations.

A test engineer managed data recording from a color graphical DA interface on a 19” Sun monitor. This test station presented the ADI advisories superimposed over a spatial display of traffic.

Participants

A multi-disciplinary test team of controllers and researchers conducted the test at Denver ARTCC and Denver International Airport. At Denver ARTCC, a total of four facility controllers worked as test controllers, with two participating during each test period. In addition to the test controllers, forty-one Denver ARTCC sector controllers participated in the test by evaluating DA advisories and issuing DA-based clearances during the course of the test. Four test engineers and two sector observers worked to conduct the test at the Denver ARTCC. Figure 1 provides an overview personnel location on the facility's operational floor.

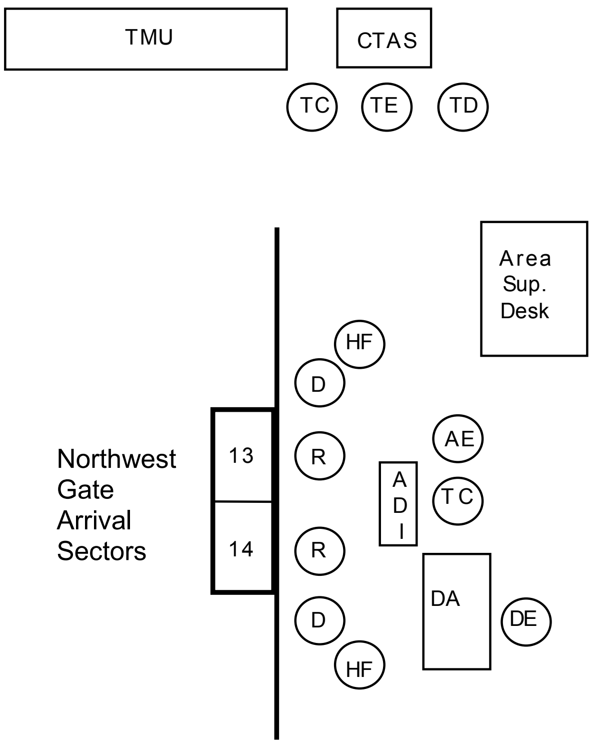
At Denver International Airport, investigators collected pilot feedback regarding the descent procedure (Palmer, et al., 1997). The remainder of this report focuses on Denver ARTCC data collection activities.

PROCEDURES

Test procedures and phraseology were developed collaboratively with input from DA researchers, Denver ARTCC controllers and pilots representing the participating airlines. The CTAS descent procedure was published and distributed by Jeppesen. Prior to the beginning of the test, both the test and sector controllers participated in training sessions. The sector controllers received training regarding the objectives of the test, the descent procedure and the associated phraseology. Test controllers received this training in addition to training on the use of the ADI.

ATC Procedures

Tests were manually conducted twice a day during arrival rush periods. During each test period, the test director worked in the Traffic Management Unit, coordinating with Traffic Management Coordinators to identify candidate test flights. Initial selection was based on test needs and minimizing the impact on normal operations. Once candidate flights were identified, the test director coordinated with United Airlines Dispatch and in some cases directly with flight crews through the use of ACARS.



Abbreviation	Title
TMU	Traffic Management Unit
TE	Test Engineer
TD	Test Director
CTAS	CTAS displays
HF	Human Factors Observer
D	D-side Controller
R	R-side Controller
ADI	Auxiliary Display Interface
AE	Auxiliary Engineer
TC	Test Controller
DA	DA workstation
DE	DA Engineer

Figure 1. Test personnel location on operational floor

When a candidate aircraft was identified, the test and auxiliary engineers and the test controller began monitoring the aircraft at the ADI. First, the test controller interacted with the ADI to review the aircraft advisories to assess the conditions for conducting the test. If desirable, the test controller modified the advisory to conform with the traffic situation. The test controller then delivered the advisory to the sector controller on a written form. The sector controller evaluated the advisory, and if necessary proposed alternative clearances. Any desired modifications were coordinated with the test controller, who updated the ADI accordingly. This approach was necessary because the sector controller, who is responsible for traffic, did not have access to DA. Once the sector controller accepted the advisories, the test controller monitored communications and reported any questions or comments from the flight crew and sector controller. Sector observers also monitored and recorded key events at each test sector.

The test and auxiliary engineers were primarily involved with the collection of data and tracking the progress of each participating flight. This included recording test controller interactions with the ADI, aircraft track information, controller/pilot communications and ensuring that all relevant information was recorded and issued to the participating flights for each phase of flight.

Following each test session, questionnaire data was collected from the test controllers and the sector controllers, as staffing allowed. Sector controllers were asked to complete questionnaires rating the acceptance of advisory use and how advisory use affected specific aspects of their workload. Debriefing interviews were also conducted to identify anomalous traffic situations that may have occurred during the run. Controller strategies, workload, and CTAS descent procedure and system acceptance were also addressed. All participants completed a demographic questionnaire.

Flight Procedure

The CTAS flight procedure changed the current arrival procedure by providing a specified top of descent (TOD) point and by providing this information to the flight crew before the TOD, thus enabling them to maximize the use of VNAV during their descent. It should be noted that descent speed is often used to accomplish and maintain spacing under current procedures.

Phraseology

The test phraseology included a notification clearance that was required due to the test procedures. The notification clearance informed pilots they were being invited to participate in the test and gave them an opportunity to decline.

The CTAS phraseology for jets was modified during the course of the test. The Jet Descent and Continuation clearances were modified because some controllers felt that the initial phraseology did not adequately reinforce information regarding the CTAS procedure that was also available to flight crews on the CTAS Jeppessen chart. The following are the initial and modified clearances for jet aircraft.

<u>Jet Notification</u>

[ACID] expect CTAS descent. Expect to cross [Fix] at FL __ and 250 knots. Maintain FL __.

<u>Jet Descent</u>

original:
[ACID] maintain FL __ until __ miles E/W of [Fix]. Descend and maintain FL __. Maintain __ Mach/ __ knots in the descent.

modified:
[ACID] maintain FL __ until __ miles of [Fix]. Descend and maintain FL __. In the descent, maintain Mach __ until reaching __ knots.

Jet Continuation

original:
[ACID] continue descent at __ knots. Cross [Fix] at and maintain FL __ and 250 knots.

modified:
[ACID] in the descent maintain __ knots. Cross [Fix] at and maintain FL __ and 250 knots.

Turbo prop phraseology did not require any modifications. Also, most of the turbo prop cruise altitudes were within the low altitude sectors. Therefore, a continuation clearance was not required. The turbo prop phraseology follows.

Turbo Prop Notification

[ACID] expect CTAS descent. Expect to cross [Fix] at __.

Turbo Prop Descent

[ACID] maintain FL __ until __ miles E/W/N/S of [Fix]. Cross [Fix] at and maintain __. Maintain __ knots in the descent.

RESULTS

Demographics

Twenty-one sector controllers, who analyzed the advisories at the sectors, completed demographic surveys. These controllers had a mean of 12 years of ATC experience, with 9.2 years of experience in Level 5 facilities and 7.8 years at Denver ARTCC.

Questionnaires

Sector controllers completed two questionnaires in which they rated they workload associated with and acceptability of evaluating and issuing DA-based advisories. Thus, the ratings reflect the sector controller evaluation of the DA concept rather than a rating of the system as it existed during the test.

Each questionnaire used a ten-point rating scale. The first questionnaire elicited controller ratings of the performance support provided by DA advisories, in terms of workload. The ratings anchors were "Made my job more difficult," which was equivalent to one, "Had no effect," which was equivalent to five, and "Made my job easier," which was equivalent to ten. The scale was designed to have an internal baseline for workload, since it was not possible to collect separate baseline data.

During the test periods, controllers performed a variety of tasks to exercise the range of functions available with DA. Some of these tasks are not regularly needed during nominal operating conditions (e.g., good weather). Therefore, it was not possible to collect baseline data during separate, equivalent traffic periods. To compensate, controllers were asked to provide ratings comparing their experiences while performing these tasks without DA. Ratings were elicited for the effect of advisory use on the following items: mental calculations, number of decisions, amount of planning, amount of communication and coordination, types of mental calculations, types of decisions, planning, integration of information from multiple sources, types of communication and coordination and the overall amount of support provided by the advisories.

The second questionnaire also used a ten-point scale. It addressed the acceptance of system use as it affected the following items: number and types of mental calculations, number and types of decisions, amount and types of planning, integration of information from multiple sources, number and type of communications and coordination, number and types of inputs to the system, system response time and overall acceptance of the system concept. The scale anchors were "Completely Unacceptable," which was equal to one, and "Completely Acceptable," which was equal to ten.

As shown in figure 2, sector controller workload ratings indicate that the use of DA advisories did not increase sector controller workload involved with

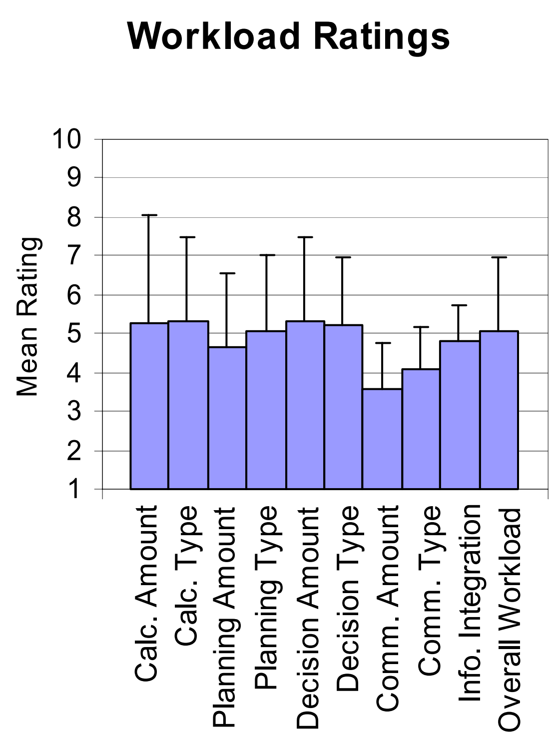


Figure 2. Workload Ratings by Category

making decisions, the number of decisions, formulating plans, the amount of planning, performing mental calculations, or the number of calculations. Integrating information from an additional source did not affect workload. In contrast, increased workload was associated with the type and number of communications.

Sector controller ratings of system concept acceptance generally ranged between seven and eight, indicating a moderately positive level of acceptance (see figure 3). The highest acceptance ratings were observed relating to support for the types of calculations and types of decisions performed by controllers. The lowest acceptance rating was associated with the number of communications required with DA use.

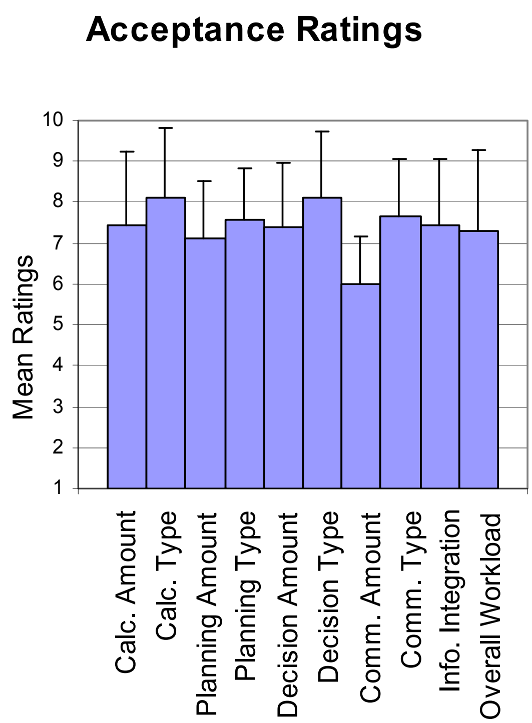


Figure 3. Acceptance Ratings by Category

DISCUSSION

There are three primary human factors findings. First, sector controllers were able to use DA-based advisories to support clearance generation. In other words, the controllers were willing to evaluate advisories and use them in the formulation of clearances in operational conditions. Furthermore, the use of advisories in this manner did not result in increased workload ratings, with the exception of type and amount of coordination. Moderately high acceptance ratings may be a product of the increased accuracy achieved with DA use in combination with the maintenance of current workload levels for specific controller activities. However, it should be noted that sector controllers were not physically interacting with DA. Therefore, these results represent the acceptance of the system proof of concept, not the operational acceptability of the system used during the test.

Second, test controllers successfully used the prototype interface. They primarily interacted with the alphanumeric display, and were able to extract information from, and make inputs into, the system under real-time operational conditions. Again, these results should be considered in the context of use; test controllers were not controlling traffic while interacting with the display. Controllers have since provided input to a re-design of the tool's graphical user interface (Laudeman, Brasil & Stassart, 1998). This graphical interface was used in subsequent simulations and field tests (McNally, Bach & Chan, 1998).

Third, the DA phraseology needed modifications during the course of the evaluation and requires further refinement to reduce clearance length and increase clarity. The clearance modifications made during the test were meant to increase clearance clarity by providing redundant information regarding the CTAS descent procedure within the phraseology. Analyses of the phraseology and descent procedures showed that clearance length and the use of the continuation clearance, which was necessary due to sector boundaries, were complicating factors that should be addressed prior to the operational use of the descent procedure (Palmer, et al., 1997). A full-mission 747-400 simulation experiment conducted in 1996 showed that a 30% reduction in descent clearance transmission time could be achieved by modifying the DA procedure and clearances. However, readback errors observed in this experiment suggest that there is still a need to reduce the amount of information contained in DA descent clearances (Crane, Palmer & Smith, 1997; Morrow & Rodvold, 1993).

Planning, Decision-Making and Calculating

Workload ratings regarding planning and decision making activities indicate the use of DA advisories neither increased nor decreased sector controller workload. However, acceptance ratings for these factors were moderately high. These results indicate that the contents of the advisories generated by DA were reasonable given the operational conditions, and that their use was acceptable to sector controllers within their operational environment. Given that DA advisory use resulted in a perceived maintenance of workload levels, the acceptance ratings for advisory use may indicate that some planning and decision-making support was provided by the system.

Similarly, the workload ratings associated with the amount and types of calculations performed by sector controllers also indicated that workload levels were maintained at current levels with DA use. Again, moderately positive acceptance ratings were received for the amount and types of calculations.

Communication Issues

Workload ratings for the number and type of communications were the only categories reflecting an increase in sector controller workload, with the number of communications resulting in the largest increase and the type of communication with the second largest increase. Controllers provided positive acceptance ratings for the type of communications conducted when using DA advisories. The ratings indicated lower acceptance for the number of communications conducted.

We hypothesize that the increased workload ratings and lower acceptance ratings for number of communications were an artifact of the increased communication involved in two aspects of the test. First, the amount of verbal and written communication between the test controllers and the sector controllers was considerable, given that all advisory information had to be passed between these participants. Once the controller can directly visually reference the display, the number of inter-controller communications should decrease. Second, the phraseology used in the test was longer and more complex than that used today. Part of the increase in communications is attributable to the heads-up clearance, which was provided by the sector controllers to the pilots, but would not be part of actual operations. As such, this entire communication was only needed due to the experimental nature of the test procedures. A more significant concern is the amount of information contained in the descent clearance. Research is underway to assess how this information can be conveyed more concisely and reliably.

Usability

A total of four test controllers interacted with the ADI during the course of the test. However, only two of them interacted extensively with the system. Therefore, usability data regarding data extraction and input was collected from the two most experienced controllers. Data was collected in the form of ratings. Statements regarding usability issues were presented, and controllers rated the extent with which they agreed or disagreed with the statement on a five-point scale. The following issues were identified for improvement: some symbols used in the display did not conform to air traffic symbol use, the status of advisories (e.g., locked, input) should be more prominently displayed, and the functions associated with some specific keystrokes were not easy to remember.

CONCLUSION

It is important to note that while most aspects of the system were exercised during the test, responsibilities were distributed between personnel in a manner that is inconsistent with the way in which DA might ultimately be implemented. The results should be interpreted with this limitation in mind.

Results demonstrated the ability of DA to provide useful clearance generation advisory information to the en-route controller. Controllers were willing to refer to and evaluate DA-based advisories under operational conditions and where appropriate, provide information about alternative scenarios to the system. This was accomplished with highly accurate crossing times (Green & Vivona, 1996).

Further, the human factors data illustrate that these benefits were obtained without significant increase to sector controller workload. Sector controllers reported high levels of acceptance for the DA proof of concept, and were able to incorporate the new phraseology and procedures into their operational environment. However, significant refinements to the phraseology and procedure are necessary prior to operational use.

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